

MOOROWIPORA CHAMBERENSIS, A CORAL FROM THE EARLY CAMBRIAN MOOROWIE FORMATION, FLINDERS RANGES, SOUTH AUSTRALIA

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Summary

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Moorowipora chamberensis gen. et sp. nov., an Early Cambrian coral with a morphology close to tabulates, occurs in the Moorowie Formation of the eastern Flinders Ranges. The oldest accepted tabulate coral *Lichenaria* Winchell & Schuchert first appeared in the Early Ordovician. However, it is possible that *Moorowipora chamberensis* is an early representative of the tabulates, extending their time range down to the Lower Cambrian. The tabulate-like characteristics of *Moorowipora chamberensis* include the form of the corallum, which varies between cerioid and fasciculate, the wedge-shaped to spine-like septa and generally complete, well-formed, convex-upward or undulating horizontal tabulae. *Moorowipora chamberensis* has some skeletal structures in common with the Early Cambrian species *Flindersipora bowmani* Lafuste, and *Tabulaconus kordae* Handfield, but is unlike any other previously described Cambrian coralomorph.

KEY WORDS: *Moorowipora chamberensis*, Early Cambrian, Moorowie Formation, tabulate coral, Flinders Ranges, South Australia.

Introduction

The Early Cambrian coral *Moorowipora chamberensis* gen. et sp. nov., is found in slumped reefal blocks within a megabreccia forming part of the Moorowie Formation in the eastern Flinders Ranges of South Australia. *Moorowipora chamberensis* occurs with *Flindersipora bowmani* Lafuste 1991, and at least three other previously undescribed corals at a site close to the disused Moorowie Mine (Fig. 1).

Most of the several known Cambrian coralomorphs have been regarded as doubtful early representatives of tabulate corals. They show unusual aspects in their morphology: a significant gap in time (~20 my) occurs between the Early Cambrian and the oldest accepted Early Ordovician tabulate coral, *Lichenaria* Winchell & Schuchert 1895 (Scrutton 1979; 1984; 1992). *Moorowipora chamberensis* has structural characteristics suggesting its affinity with the tabulates, and is possibly an early representative of this group.

Stratigraphy and associations

The Moorowie Formation and its lateral equivalents, the Wilkawillina Limestone, Mernmerna Formation [= Parara Limestone, Dalgarno & Johnson (1962)] and Oraparinna Shale, form part of the Early Cambrian Hawker Group (Dalgarno 1964). These units are mainly limestones, calcareous shales and mudstones,

and siltstones, with minimal siliciclastic arenites, and variously reflect shallow marine, reefal, shelf-margin, slope and basinal environments of deposition.

The corals occur within reefal boundstones that have tumbled as large talus blocks to form a megabreccia, which comprises the middle part of the Moorowie Formation (Mount 1970¹; Hart 1989²; Lafuste *et al.* 1991; Savarese *et al.* 1993). This stratigraphic level represents part of a suggested third transgressive/highstand phase of the Early Cambrian (Gravestock & Hibbert 1991).

The talus blocks of the Moorowie Formation, analagous to those in contemporaneous reefs, comprise Type 5 shelf margin build-ups (James & Gravestock 1990). The reefal system was established in a high energy marine environment encroaching on a marginal fan (Savarese *et al.* 1993). The fan comprises coarse breccia and is suggested to have formed as a result of local diapiric activity. However, we have not observed any reef structures in their original placement.

Coral colonies, together with archaeocyaths and the calcimicrobes *Renalcis* Vologdin 1932, *Girvanella* Nicholson & Etheridge 1878 and *Epiphyton* Borneman 1886 occur in transported reefal blocks, which vary from cobble size to about 10 m in maximum dimension. Within individual blocks, the organisms are commonly preserved in life position. The dominant faunal elements vary markedly between blocks, from archaeocyaths, to stromatolites and more rarely corals. These differences probably reflect mass collapse of different parts of a zoned reef complex of reasonably wide areal extent (the distinctive biofacies represented surely formed in areas some hundreds of metres broad implying that the main reef front had a fringing geometry). The rapid slumping of the talus into deeper water (presumably the fore-reef) probably protected the carbonate frameworks from vadose

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¹ MOUNT, T. J. (1970) Geology of the Mount Chambers Gorge region. B.Sc. Hons. thesis The University of Adelaide (unpubl.).

² HART, J. (1989) Lower Cambrian corals from Archaeocyathan-*Epiphyton* clasts within the Moorowie Formation megabreccia, northern Flinders Ranges, South Australia. B.Sc. Hons thesis, The University of Adelaide (unpubl.).

diagenesis, resulting in the remarkably pristine preservation of the fauna. The corals commonly form encrusting to upright, tall colonies, the latter up to 60–70 cm high. Individual colonies tend to be widely spaced.

Flindeispora bowmani has been found in bioherms in the lower Orparinna Shale at Ten Mile Creek (Fig. 1), as well as near the Moorowie Mine (Lafuste *et al.* 1991). At Ten Mile Creek, trilobite and echinoderm fragments form hash beds in the Orparinna Shale, and associated archaeocyaths have been correlated with Faunal Assemblage 9 (Daily 1956), which equates with the *Pararaia juncea* Zone of Jell (1990; Lafuste *et al.* 1991). This stratigraphic correlation indicates that the Moorowie Formation is Botomian in age.

Preservation

Although complete recrystallization of the colonies has occurred, an indication of the primary micro-

structure of the skeleton can be seen in some patchy domains. Edges of the possible primary biocrystal platelets are distinguished by crenate to wavy lines of minute inclusions within the much coarser crystals comprising the recrystallised fabric. Narrow, lath-like zones showing irregular extinction under polarised light occur at some places approximately transverse to skeletal elements where secondary carbonate crystals penetrate the coral skeleton. This suggests a residual overprint of the original mineralogy disturbing the optical continuity of the subsequent recrystallisation. Apart from recrystallised spar, cavities surrounding corallites and within the calices may be filled with very fine sand or silt. It appears that during life, part or whole colonies may have been temporarily covered with a thin layer of sediment causing the death of some zooids. The survivors rejuvenated new parts of the corallum. Some colonies seem to have been eroded by rapid, energetic influxes of coarse sand (also noted on calcimicrobe encrustations and archaeocyaths), allowing only a few corallites to continue their growth. Fractures post-date growth and are often filled with very fine sediment (Figs 2 and 3C).

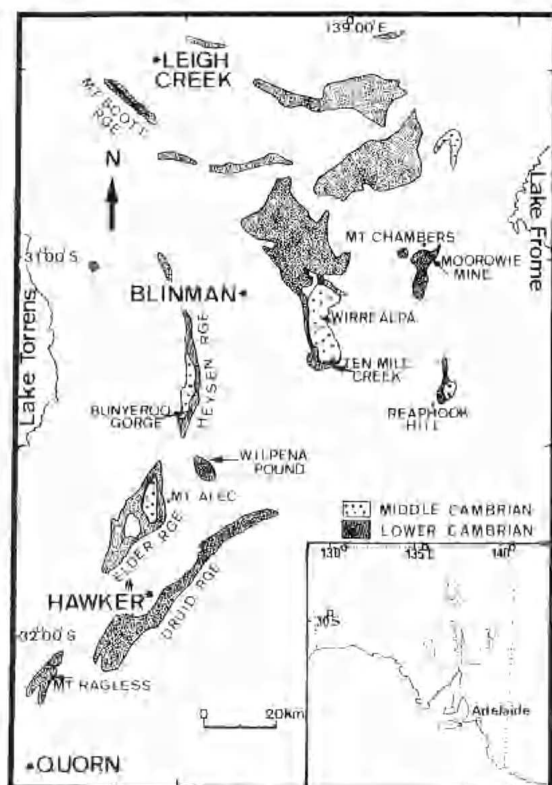


Fig. 1. Location map showing fossil occurrence near the Moorowie Mine and the distribution of Early and Middle Cambrian outcrops in the Flinders Ranges of South Australia.

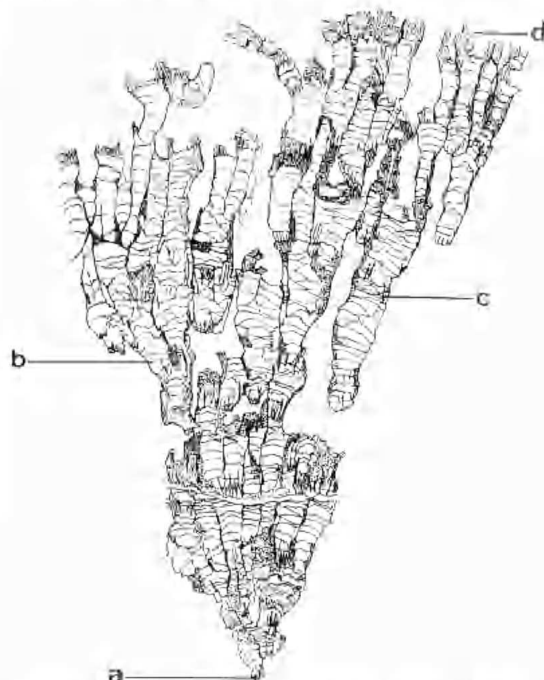


Fig. 2. Interpretive sketch (longitudinal section) of holotype SAM P34165 illustrating cone to fan shaped colony: the form of individual corallites: protocorallite (a); tabulae (b); septa (c); calice (d); lateral increase (top centre and right) and peripheral intracalicular increase (x 2).

Fig. 3. Longitudinal sections of holotype SAM P34165, illustrating parts of the colony (see Fig. 2). A & B – Top of the colony with walls extending above the corallum, methods of increase and corallite structure; C – base of colony (x 4); and D – Higher magnification of (B) showing normal and thickened tabulae (lower left); and oblique projections of the outer wall (centre, right) (x 15).



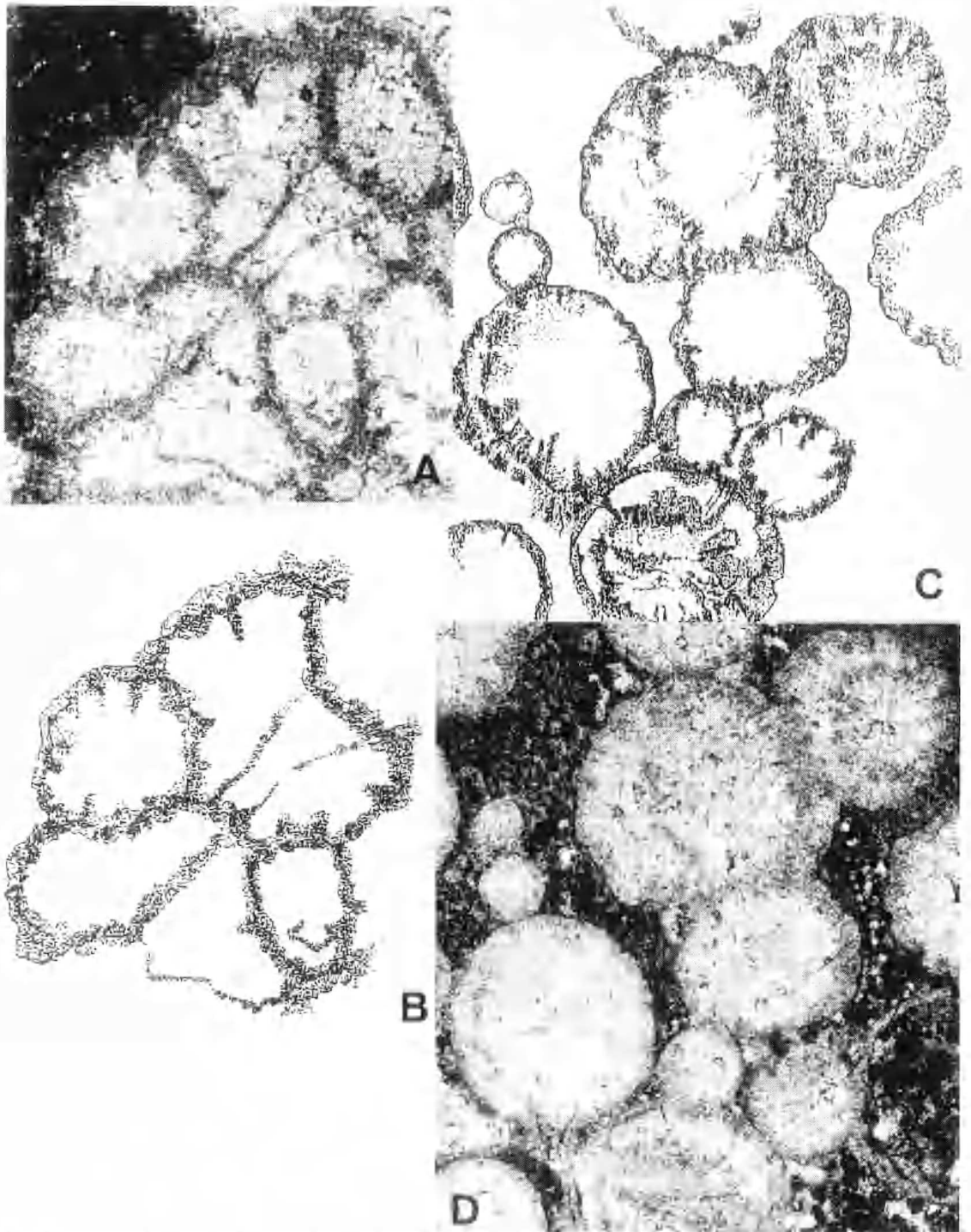


Fig. 4. Transverse sections and interpretive sketches of holotype SAM P34165: (A & B) cerioid ($\times 10$) and (C & D) fasciculate ($\times 10.5$) areas of the corallum. Differences can be seen in corallite shape, septa, and new walls across corallites formed during offset formation. Rejuvenation of corallites (C & D) is evident top right and bottom centre.

The term 'platelet' (Lafuste *et al.* 1991), is used to describe relic microstructural elements of the skeleton.

Systematic palaeontology

Phylum: CNIDARIA
Class: ANTHOZOA
Subclass: ?TABULATA
Family: uncertain

Genus: *Moorowipora* gen. nov.

Type species: *Moorowipora chamberensis* sp. nov.

Etymology: For the type locality near the Moorowie Mine in the eastern Flinders Ranges of South Australia.

Diagnosis: Corallum small, varying from massive cerioid to fasciculate, comprising polygonal, oval or rounded corallites. Corallites are long, tuberoid to irregularly cylindrical. Walls are thin, wavy to crenate, rarely straight. Tabulae are irregularly spaced, mostly complete, concave upwards to undulating horizontal. Septa absent, or number up to 20 in each corallite. Where present, septa are randomly spaced, short and form wedge to spine-like projections into corallites, arising from inward angulations of the wall. Pores appear to be absent.

Moorowipora chamberensis sp. nov.

FIGS 2-7

Etymology: For nearby Mt. Chambers.

Diagnosis: As for genus.

Type specimens: The specimens described in this paper are held at the South Australian Museum (SAM). **Holotype** SAM P34165, four thin sections, SAM P34165-1; SAM P34165-2; **Paratypes** SAM 34166-1; SAM P34166-2.

Material: The holotype, paratypes as well as several other colonies come from one rock sample measuring 270 mm long, 230 mm wide and 120 mm thick; taken from a large boulder within the Moorowie Formation, near the Moorowie Mine in the eastern Flinders Ranges.

Description: In transverse section (Figs 4, 5), corallites show gradation into two distinct habits, massive cerioid and fasciculate dendroid. In fasciculate habit, corallites rarely touch, are circular to slightly oval in shape and vary in diameter from 0.95 to 3.75 mm. Corallites with massive habit are rather irregularly shaped 5 or 6 sided polygons, sometimes oval or rectangular, rarely circular; they vary individually in diameter from 0.77 to 3.5 mm.

Walls are thin, varying between 0.1 mm and 0.15 mm in thickness and show a relic fibrous structure (Figs 4-6).

A midline is apparent between many adjoining corallites. Walls are wavy to slightly crenate, being rounded in isolation or adjacent to small spaces in the corallum, with a tendency to become straighter and less distinct where they merge with the walls of adjoining corallites.

In longitudinal section (Figs 2, 3), each colony is generally small, numbering from 2 or 3 to about 16 corallites. Colonies are either cone- to fan-shaped, diverging outward from a single protocorallite, or more rectangular, where they appear to arise from several adjacent corallites. Increase is both lateral and peripheral intracalicular, producing 1, 2 or more offsets (Fig 2, 3A).

Individual corallites are tuberoid to irregularly cylindrical in shape and vary greatly in width and length (up to 19.5 mm); prior to increase (formation of a new corallite). The base is rounded and blunt, the protocorallite producing 3 or 4 short septa prior to the formation of an initial tabula. The calice is prominent extending between 2.5 and 4.75 mm past the last tabula (Figs 3B, 3D).

Tabulae are mostly complete, mainly convex-upward or undulating horizontal, often down-turned where they meet the wall (Figs 2, 3). They are irregularly spaced, but commonly occur at the same level in adjacent corallites. The distance between them is highly variable (0.35 to 2.1 mm), while the thickness of tabulae varies from 0.002 mm to 0.01 mm.

Septa number up to 20 in fasciculate corallites; are very short (0.01-0.2 mm), generally equal in length, triangular to wedge-shaped, often indistinct. They form protrusions of the wall of the corallite at sites of inward creasing (Figs 4, 5). In massive, cerioid corallites in the main body of the corallum, there may be up to 10 septa or septa may be absent. Septa are randomly spaced; long and short septa may alternate, or only long or short septa may be present. Septa are wedge to spine-like in shape. Septa are generally longer than in the fasciculate corallites. In longitudinal section septa are observed as continuous vertical laminar plates intersecting normally with tabulae.

Microstructure: The microstructure was studied at magnifications up to $\times 200$, and photographs were taken under polarised light.

In transverse section at low magnification (Figs 4, 5) relic fibrous elements which form the sclerenchyme and apparently represent indications of original bio-crystals appear as continuous lineae across the wall and into the septa. At higher magnification (Fig. 6) the interlocking fibrous elements form triangular to rectangular bundles, composed of narrow parallel-sided

and blade-like geniculate structures up to $164 \mu\text{m}$ long and $37 \mu\text{m}$ wide. These are angled towards and away from the centre of each corallum. The bundles have the appearance of crossing, or being stacked over underlying layers. Near the midline of walls the fibres are often less oblique and have a slightly different orientation, appearing to be broader and more randomly oriented.

In longitudinal section at magnifications of $\times 100$ to $\times 200$, the midplane of the wall seems to have been composed of irregularly shaped, crenate, interlocking platelets which individually represent the fibrous lineae of transverse cuts. Platelets may be almost rectangular, vertical to slightly inclined, occasionally almost horizontal in the middle of the wall. They commonly occur diverging outward towards the top of corallites (Fig. 7). Wall platelets are more elongate and wider than the fibre bundles seen in transverse section, being up to $190 \mu\text{m}$ in length and $138 \mu\text{m}$ in width.

Tabulae are continuous with the inner edge of the wall, which converges slightly around them. The structure of the tabulae is similar to the septa and wall

in transverse section, with bundles of fibres being mainly triangular, or irregularly shaped. Triangular bundles of fibres are up to $360 \mu\text{m}$ in length, and $308 \mu\text{m}$ in width. In tabulae of normal thickness, adjoining triangular bundles interlock forming a crenate

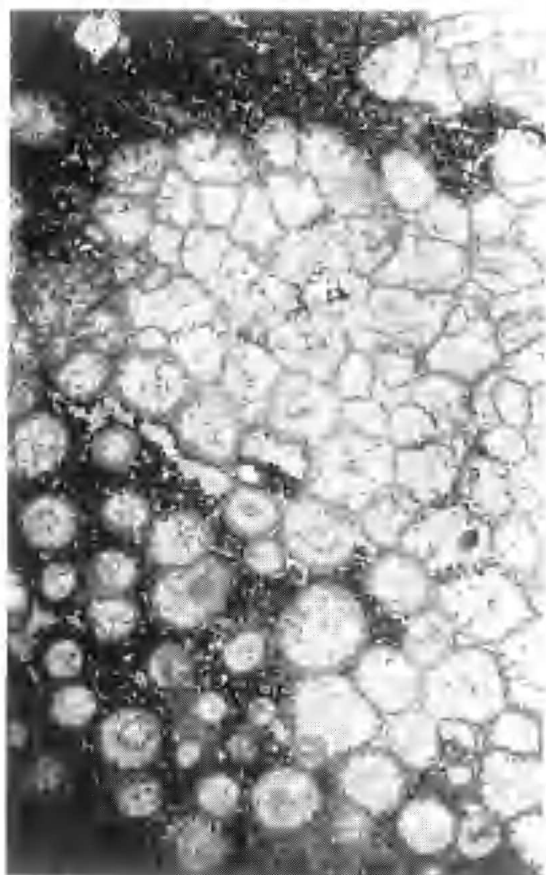


Fig. 5. Transverse section of holotype SAM P34165; part of corallum showing both cerioid and fasciculate areas ($\times 3.3$).

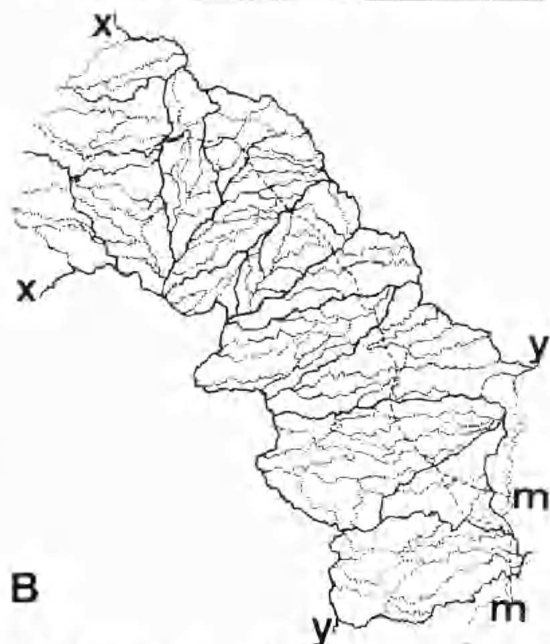
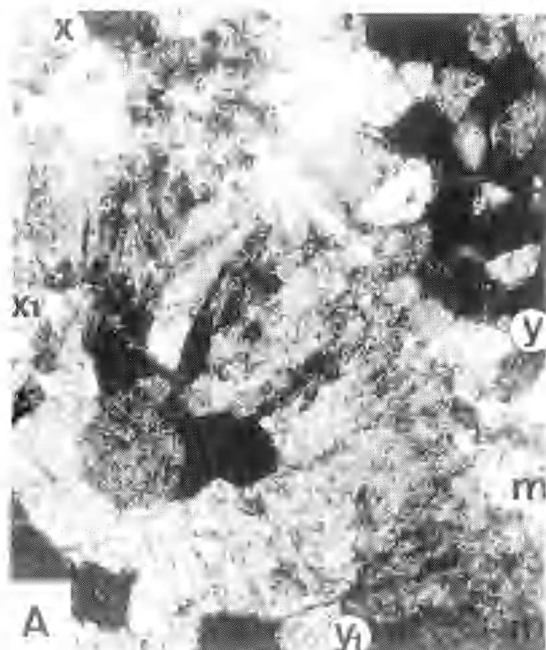


Fig. 6. Transverse section and interpretive sketch of holotype SAM P34165; illustrating triangular and rectangular bundles of fibres extending across the walls of the corallite. x - $x1$ and y - $y1$ define boundaries of illustration, m is midline of the wall ($\times 44$).

upper and lower surface. A more complicated interlocking pattern is formed in thickened tabulae.

Remarks: *Moorowipora chamberensis* is dimorphic in both the morphology of the colony and the method of increase. Dimorphism often occurs in tabulates and may be shown as differences in corallite size, shape and internal structures (Oliver 1968, 1975). Many intraspecific variations are probably environmentally controlled, being influenced by factors including the adjacent sediment, and the position of corallites within a colony (Oliver 1968). The two different morphological forms observed in *M. chamberensis* probably reflect the mode of increase, which also appears to be dimorphic, being related to the position of individual corallites within the corallum. Corallites within the fasciculate area, which generally occurs at the outer edges of the colony, appear to have resulted from lateral increase. Offsets branch away from the main colony producing isolated corallites which rarely touch and are therefore unaffected by crowding (Figs 2, 5). Such corallites are thus round to slightly oval

in transverse section. Peripheral intracalicular increase is most common in the massive, eerioid parts, and where a solitary corallite has become established (Figs 2, 3). Usually one, two or more offsets are produced at the same time, with new walls growing from sites of septal insertion across the calice. Both methods of increase commonly occur at different stages of growth within the same corallite, and are probably related to the amount of space surrounding it.

The variable distance between tabulae and the presence or absence of septa do not appear to be linked to any particular stage of growth, a characteristic which has been suggested as possibly occurring in some tabulates (Hill 1981). Septa primarily occur in the protocorallite and immature corallites, while at other stages of growth they may or may not be present.

Discussion and Conclusion

When compared with other Cambrian corals suggested to have tabulate affinities (Scrutton 1979), *Moorowipora chamberensis* is closest in its morphology to *Tabulacornis kordae* Handfield 1969, from the Early Cambrian (Botomian) of east central Alaska and British Columbia. In vertical section, *M. chamberensis* and *T. kordae* differ in the shape of the corallites, which are more tubular in appearance in the former. Height and width vary, with mature corallites being up to 19.5 mm long and 5.0 mm wide in *M. chamberensis*, while corallites of *T. kordae* are up to 65 mm long and 27 mm in width in the colonial form (Debrenne *et al.* 1987). The tabulae also differ, being undulating horizontal to concave upward in *M. chamberensis* and either horizontal or slightly concave downward in *T. kordae*. Incomplete tabulae are more dissepiment-like and walls are generally thicker in the latter (Handfield 1969). The microstructure of both corals is significantly different in transverse section, being geniculate fibres in *M. chamberensis*, and concentric light and dark wavy laminations in *T. kordae*. Tabulae also differ, being formed from bundles of fibres extending upward and downward from a medial line in the former, unlike the two layered light and dark zones of *T. kordae*. However, platelets (longitudinal section) in the walls of *M. chamberensis* are of similar shape, but generally larger. *M. chamberensis* may belong in the family Tabulacornidae, but, the above differences, likely preclude it from this division.

M. chamberensis is distinguished from *Lipopora lissa* and *L. daseia* Jell & Jell 1976, from the Early Middle Cambrian of western New South Wales, by the presence of tabulae and the shape and arrangement of septa, although the corallites of *L. lissa* are of similar length and width. *Cambroirypa montanensis* Fritz & Howell 1955, from the Middle Cambrian of British

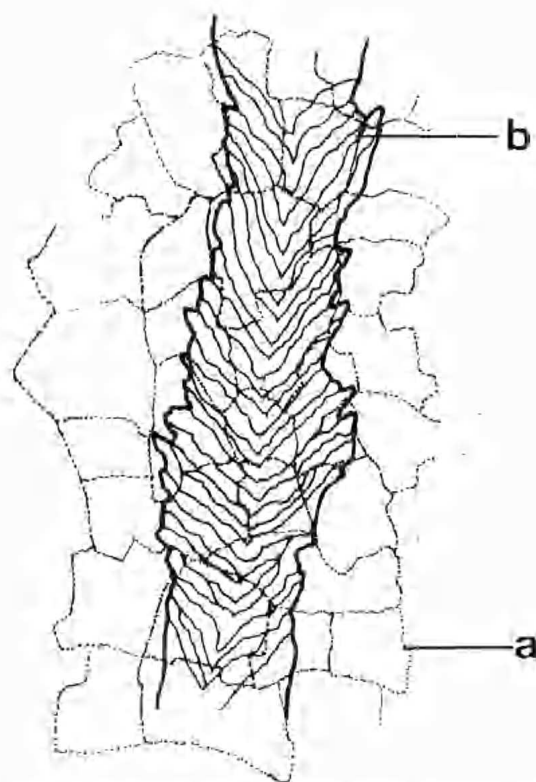


Fig. 7. Longitudinal section (cartoon sketch) showing large crystals of the recrystallisation fabric (a) incorporating the wall of compound corallites. (b) Relic biocrystal fibres diverge towards the corallum.

Columbia, is distinguished from *M. chamberensis* by the more slender corallites and the absence of tabulae and septa. Most of the Early Cambrian coraiomorphs described by Korde (1963, 1984a, b, 1986, 1990), are partly synonyms of already described khasaktiids or hydrocozoans and partly *nomina dubia* or *nulla* (Zhuravlev *et al.* 1993, p. 369).

M. chamberensis also differs from *Flindersipora bowmani* Lafuste 1991, although there are some similarities in microstructure. *M. chamberensis* is cerioid to fasciculate and has wedge to spine-shaped septa up to 0.2 mm in length arising from continuous walls 0.1–0.15 mm thick. In contrast *F. bowmani* is meandroid to cerioid, and has 6–16 strongly developed, straight to slightly curved septa up to 0.8 mm in length, with the edges of septa bearing very short blunt spines. Walls form very short segments between the septa and are 0.15–0.25 mm in thickness (Lafuste *et al.* 1991). In *F. bowmani* tabulae are mostly concave-downward and closely spaced (0.2–0.3 mm), but are undulating horizontal to concave and more regularly spaced in *M. chamberensis*. The mode of increase is by longitudinal fission in the former while both lateral and intercalicular peripheral increase occurs in the latter.

In transverse section, the microstructure of both corals is similar, with walls consisting of geniculate fibres which diverge and converge in two directions. In vertical section platelets in *M. chamberensis* are less elongate and broader when compared with *F. bowmani*.

It is considered that the genus *Lichenaria* which has a time range from the basal to the early/late Ordovician is the most ancient tabulate coral. Its colonial form is cerioid, it has a simple morphology

and tabulae, is aseptate, and may have rare mural pores (Bassler 1950; Flower 1961; McLeod 1979; Scrutton 1984; Laub 1984). *M. chamberensis* has structural characteristics which demonstrate its affinity to the tabulates (including septa, which are not present in lichenarids). These are (1) the cerioid to fasciculate form of the colony; (2) the spine-like to wedge-shaped septa; (3) its mode of increase; (4) the generally complete well-formed tabulae. The observed relic microstructure appears to be similar to the pinnately (clinogonally) fibrous structure of some tabulates (see Hill 1981, p. F452), including lichenarids, though the extent of the modifying influence of diagenesis is uncertain.

M. chamberensis with its tabulate-like characteristics may be either an early representative of the tabulates, or belong to a new group of corals with convergent evolution contributing to their similarities. These alternatives have been suggested by Lafuste *et al.* (1991) for *F. bowmani*, whereas Scrutton (1992), regards the latter possibility as most likely. The addition of *M. chamberensis* to the group of known early coraiomorphs, provides further evidence that tabulate corals may have their origin in the Early Cambrian.

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